Overview of Bituminous Baseline Study

Objective and Description

The objective of the *Cost and Performance Baseline for Fossil Energy Plants; Volume 1 (Bituminous Coal and Natural Gas to Electricity)* is to determine cost and performance estimates of the near-term commercial offerings for power plants, both with and without current technology for carbon capture and sequestration (CCS). The study uses consistent design requirements for all technologies examined, as well as up-to-date performance and capital cost estimates. The study timeframe focuses on plants built now and commissioned in 2010. Each plant is built at a greenfield site in the midwestern United States.

The fossil energy plant cost and performance estimates presented in the study can be used as a baseline for additional comparisons and analyses. These systems analyses are a critical element of planning and guiding Federal Fossil Energy research, development, and demonstration.

Twelve different power plant configurations are analyzed in the Bituminous Baseline Study. These six configurations include integrated gasification combined-cycle (IGCC) cases utilizing General Electric Energy (GEE), ConocoPhillips (CoP), and Shell gasifiers; four pulverized coal (PC) cases, two subcritical and two supercritical, and two natural gas combined-cycle (NGCC) plants. Each configuration was analyzed with and without CCS. The study matrix is provided in Table 1.

Table 1. Study Matrix

Plant Type	Standard Conditions (psig/°F/°F)	Gas Turbine	Gasifier / Boiler	Acid Gas Removal / CO_2 Separation / Sulfur Recovery	CO_2 Capture (%)
IGCC	1,800/1,050/1,050	F-Class	GEE	Selexol/ - /Claus	–
			CoP	MDEA/ - /Claus	–
			Shell	Sulfinol-M/ - /Claus	–
	1,800/1,000/1,000		GEE	Selexol/Selexol/Claus	90
			CoP	Selexol/Selexol/Claus	88
			Shell	Selexol/Selexol/Claus	90
PC	2,400/1,050/1,050	–	Subcritical	Wet flue gas desulfurization (FGD)/ - /Gypsum	–
				Wet FGD/Econamine/Gypsum	90
	3,500/1,100/1,100		Supercritical	Wet FGD/ - /Gypsum	–
				Wet FGD/Econamine/Gypsum	90
NGCC	2,400/1,050/950	F-Class	Heat recovery steam generators	–	–
				- /Econamine/ -	90

Assumptions

Technical

The IGCC cases are dual-train gasification systems. Once the syngas is cleaned of acid gases and other contaminants, it is fed to two advanced F-Class combustion turbines (232 MWe gross output each) coupled with two heat recovery steam generators (HRSGs) and a single steam turbine to generate roughly 750 MWe gross plant output (about 630 MWe, net). The CCS cases require a water-gas-shift (WGS) and a two-stage Selexol system to capture the carbon dioxide (CO_2), as well as compressors to raise the CO_2 to the pipeline requirements of 15.3 MPa (2,215 psia). These CCS systems require a significant amount of extraction steam and auxiliary power, which reduces the output of the steam turbine and reduces the net plant power to about 520 MWe. Because the IGCC system is constrained by the discrete F-Class turbine size, the system cannot be scaled to increase the net output to match that of the cases without CCS.

All four PC cases employ a one-on-one configuration comprising a state-of-the-art PC steam generator and steam turbine. The boiler is a dry-bottom, wall-fired unit that employs low-nitrogen oxides (NOx) burners with over-fire air and selective catalytic reduction for NOx control, a wet-limestone, forced-oxidation scrubber for sulfur dioxide (SO_2) and mercury (Hg) control, and a fabric filter for particulate matter (PM) control. In the cases with CCS, the PC plant is equipped with the Econamine FG Plus™ process. The coal feed rate is increased in the CCS cases to increase the gross steam turbine output and account for the higher auxiliary load of carbon capture and compression. The ability of the boiler and steam turbine industry to match unit size to a custom specification has been commercially demonstrated, enabling a common net output of 550 MWe for the PC cases in this study.

Table 2. Coal Analysis

Rank	Bituminous	
Seam	Illinois No. 6 (Herrin)	
Source	Old Ben Mine	
Proximate Analysis (weight %)[1]		
	As Received	Dry
Moisture	11.12	0.00
Ash	9.70	10.91
Volatile matter	34.99	39.37
Fixed carbon	44.19	49.72
Total	100.00	100.00
Sulfur	2.51	2.82
Higher heating value, Btu/lb	11,666	13,126
Lower heating value, Btu/lb	11,252	12,712

[1]The above proximate analysis assumes sulfur as a volatile matter.

Both the IGCC and PC cases utilize Illinois No. 6 bituminous coal. An analysis of the coal used is provided in Table 2.

The NGCC cases use two F-Class turbines, each generating a gross 185 MWe. The two turbines are coupled with two HRSGs and one steam turbine generator in a multi-shaft 2x2x1 configuration. For the CCS cases, CO_2 is removed in an Econamine FG Plus™ process that imposes a significant auxiliary power load on the system and requires significant extraction steam, reducing the steam turbine power output. Similar to the IGCC cases, the NGCC cases are constrained by the combustion turbine size. The NGCC cases have a total net power output of 560 MWe without CCS and 482 MWe with CCS. In all CCS cases, the compressed CO_2 is transported 50 miles via pipeline to a geologic sequestration field for injection into a saline aquifer. In addition to transport and storage, the CO_2 is monitored for 80-years.

Table 3. Environmental Targets

Pollutant	IGCC	PC	NGCC
SO_2	0.0128 lb/MMBtu	0.085 lb/MMBtu	Negligible
NOx	15 ppmvd @ 15% Oxygen	0.07 lb/MMBtu	2.5 ppmvd @ 15% Oxygen
PM (filterable)	0.0071 lb/MMBtu	0.013 lb/MMBtu	Negligible
Hg	> 90% capture	1.14 lb/TBtu	N/A

Environmental

The environmental approach for the study was to choose environmental targets for each technology that meet or exceed regulatory requirements. The IGCC targets were chosen to match the design basis of the Electric Power Research Institute for their *CoalFleet for Tomorrow Initiative*. Best Available Control Technology was applied to each of the PC and NGCC cases, and the resulting emissions were compared to 2006 New Source Performance Standards limits and recent permit averages.

Table 4. Major Economic Assumptions

Startup date	2010
Cost year (U.S. dollars)	2007
Coal cost ($/MMBtu)	1.80
Natural gas cost ($/MMBtu)	6.75
Capacity factor (%)	
IGCC	80
PC/NGCC	85
Capital charge factor (%):	
High risk (All IGCC PC/ NGCC with CO_2 capture)	17.5
Low risk (PC/NGCC without CO_2 capture)	16.4
Plant life (years)	30

Economic

The total plant cost (TPC) for each technology was determined through a combination of vendor quotes, scaled estimates from previous design/build projects, or a combination of the two. Total plant cost includes all equipment (complete with initial chemical and catalyst loadings), materials, labor (direct and indirect), engineering and construction management, and contingencies (process and project). Owner's costs are not included.

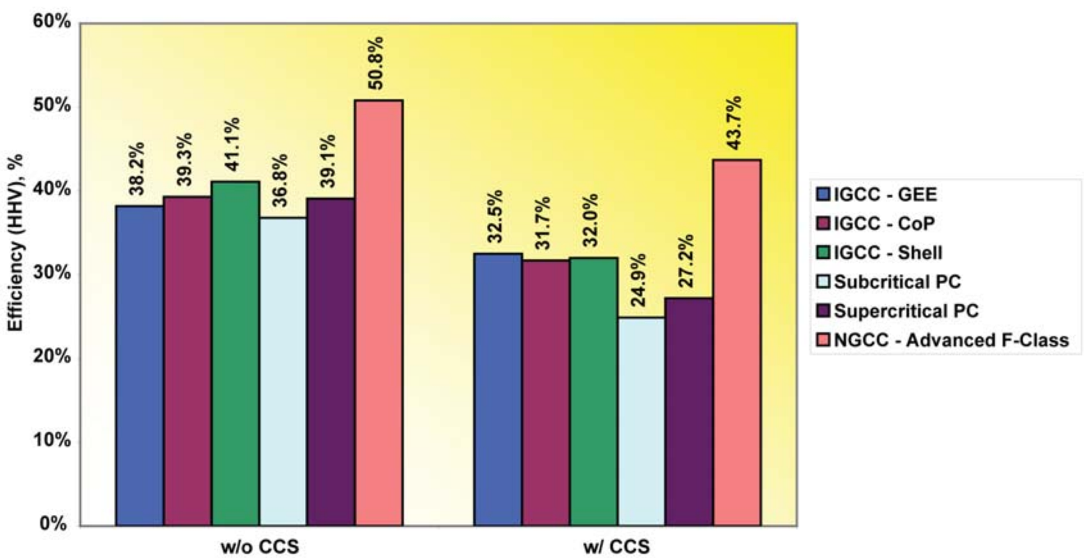
The cost estimates carry an accuracy of ±30 percent, consistent with the screening study level of design engineering applied to the various cases in this study. All cases were evaluated under the same set of technical and economic assumptions allowing meaningful comparisons among the cases evaluated.

Table 4 lists the major economic assumptions. In this study, dual trains were used only when equipment capacity required an additional train, and no redundancy was employed other than normal sparing of rotating equipment.

For those cases that feature CCS, capital and operating costs were estimated for CO_2 transport, storage, and monitoring. These costs were then levelized over a 20-year period.

This study assumes that each new plant would be dispatched at the time it becomes available and would be capable of generating maximum capacity when online. Therefore, capacity factor (CF) is assumed to equal availability. The CF is 80 percent for IGCC cases and 85 percent for both PC and NGCC cases.

Figure 1. Plant Efficiency



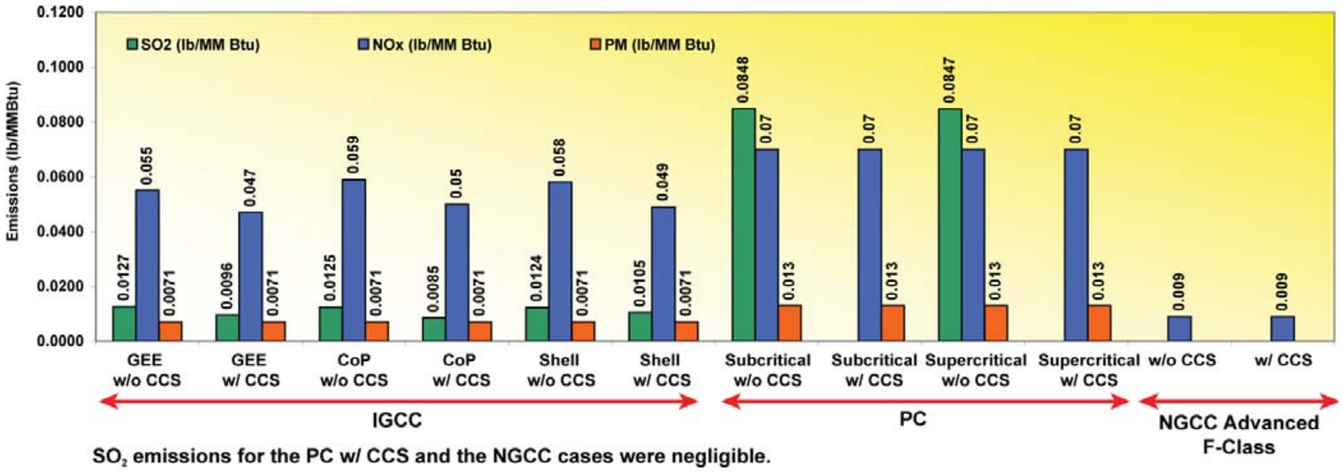
Results

Technical

For cases without CCS, the energy efficiency of NGCC is on the order of 50 percent (higher heating value, HHV basis); followed by supercritical PC and IGCC, both about 40 percent (HHV basis); and subcritical PC, with an efficiency of about 37 percent (HHV basis). Figure 1 shows the relative energy efficiency of each technology case.

With CCS, the energy penalty is 12 percentage points for PC plants, 7 percentage points for NGCC, and 6-9 percentage points for IGCC. Even with CCS, NGCC still maintains the highest efficiency of the plants evaluated at over 40 percent (HHV basis). The significant energy penalty for the PC plants reduces the efficiency to about 26 percent (HHV basis). IGCC has an efficiency advantage over PC in the CCS cases primarily because the CO_2 is more concentrated in IGCC syngas than in PC flue gas, thus requiring less energy to capture. The efficiency of the IGCC plants with CCS is about 32 percent (HHV basis).

Figure 2. SO_2, NOx, and PM Emissions



SO_2 emissions for the PC w/ CCS and the NGCC cases were negligible.
PM emissions for the NGCC cases were negligible

Environmental

All cases meet or exceed the environmental requirements set forth in the study design basis. The NGCC systems are the cleanest types of fossil power plants due to the low sulfur content and lower carbon-to-hydrogen ratio of the methane fuel. IGCC plants are the cleanest coal-based systems, with significantly lower levels of criteria pollutants than the PC plants. Figure 2 compares the results for these pollutant emissions for the various technology cases.

All CCS cases were required to remove 90 percent of the carbon present in the syngas. Due to a higher methane content of the syngas in the CoP case, carbon capture was 88.4 percent. NGCC plants produce 40 percent less CO_2 than the coal-based systems. The uncontrolled coal-based systems emitted as much as 203 lb/MMBtu of CO_2, but with CCS, emissions were reduced to about 20 lb/MMBtu. Figure 3 compares the results for CO_2 emissions for the various technology cases.

All cases were required to control Hg emissions. The environmental target for Hg removal is greater than 90 percent capture for IGCC plants and an emission rate of 1.14 lb/TBtu for PC plants. Figure 4 depicts the Hg emissions results for each case.

Water usage among the plants without CCS is lowest in the NGCC cases. The IGCC plants use about one-and-a-half times as much water as do the NGCC cases, and the PC cases use more than twice the amount of water.

Figure 3. CO_2 Emissions

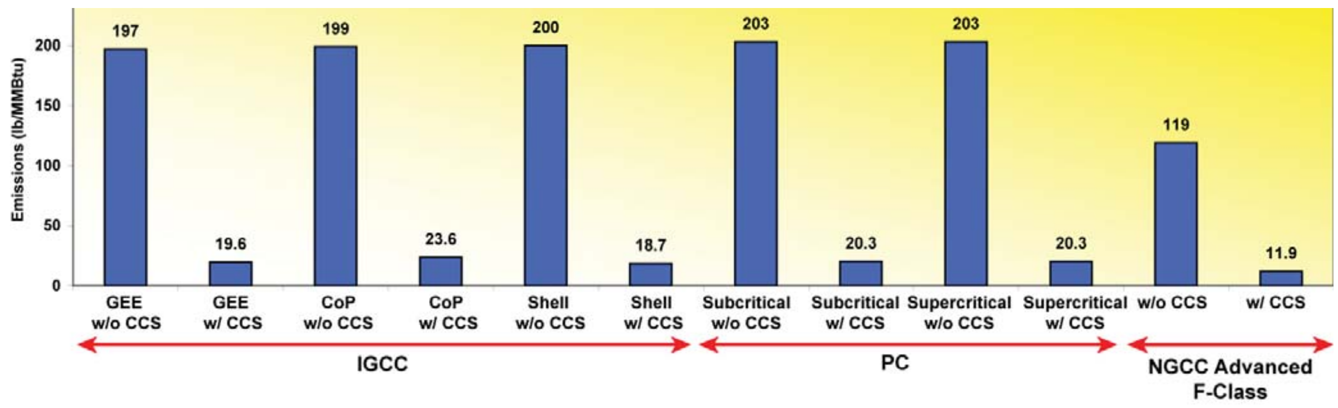
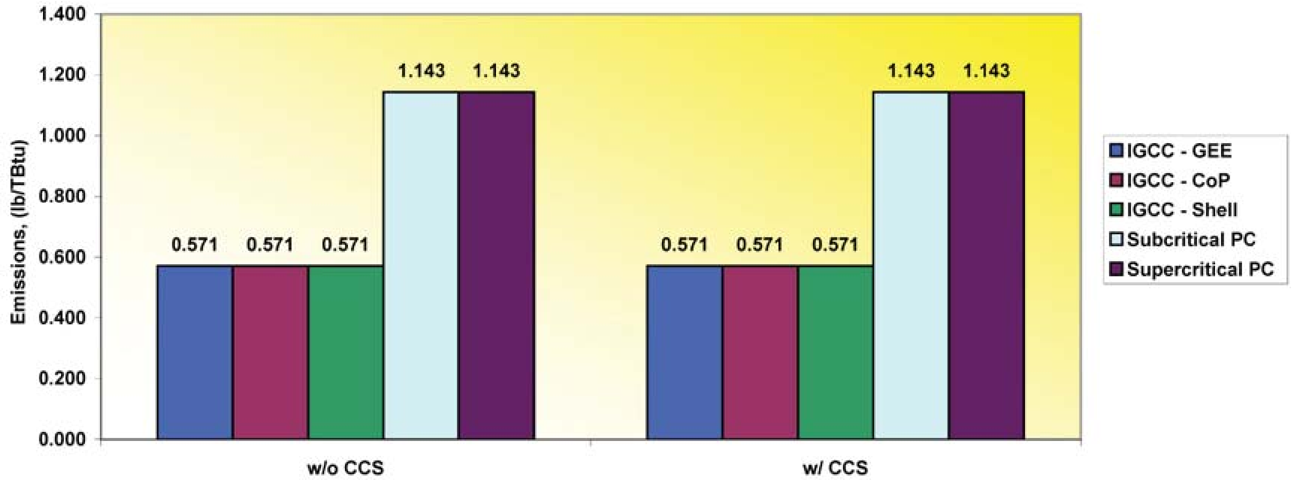
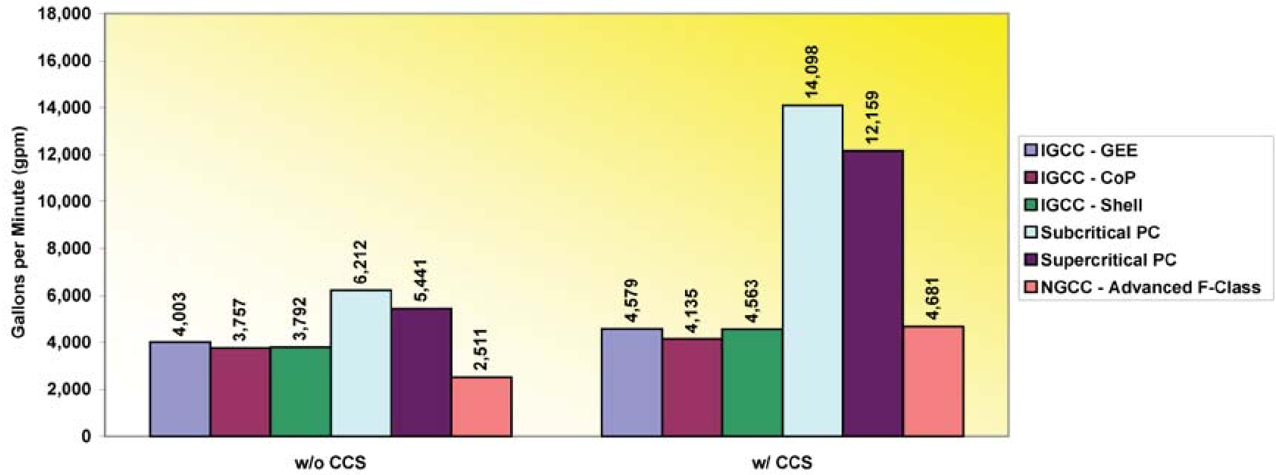


Figure 4. Mercury Emissions



Emissions for the NGCC cases were listed in the report as "Negligible."

Figure 5. Plant Raw Water Usage



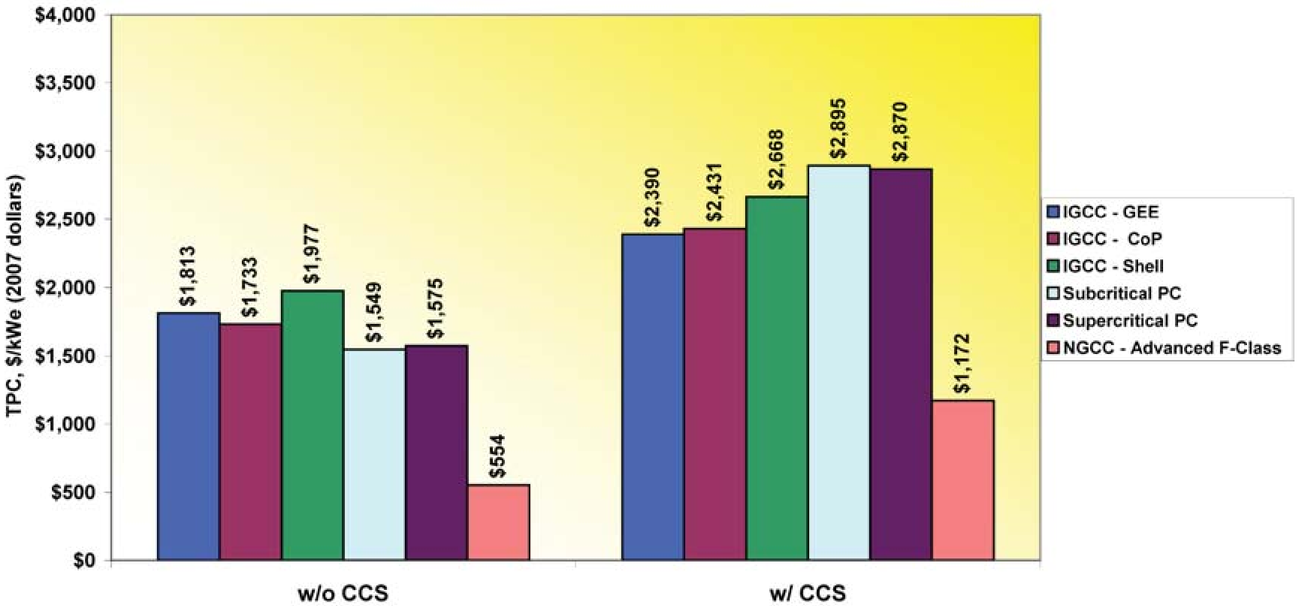
In all CCS cases, water usage increases. Water usage for IGCC cases is similar to an NGCC with CCS, whereas the PC case with CCS plants requires three to four times more water. Figure 5 shows the respective water usage rates for each technology case.

Economic

The coal-based plants have a much higher TPC than NGCC, both with and without CCS. For IGCC, the TPC is about $1,800/kWe, varying somewhat based on the gasifier type. This is about 20 percent higher than the TPC for a PC supercritical plant, which is about $1,500/kWe.

With CCS, the TPC for NGCC and PC plants ($/kW) increases by about 110 and 85 percent respectively. The TPC for the IGCC plant increases by around 35 percent. The NGCC plant capital requirement is over $1,000/kWe, while the IGCC plants cost approximately $2,400 to $2,600/kWe, and the PC plants cost over $2,800/kWe. Figure 6 shows the TPC for each technology case.

Figure 6. Plant Capital Requirements



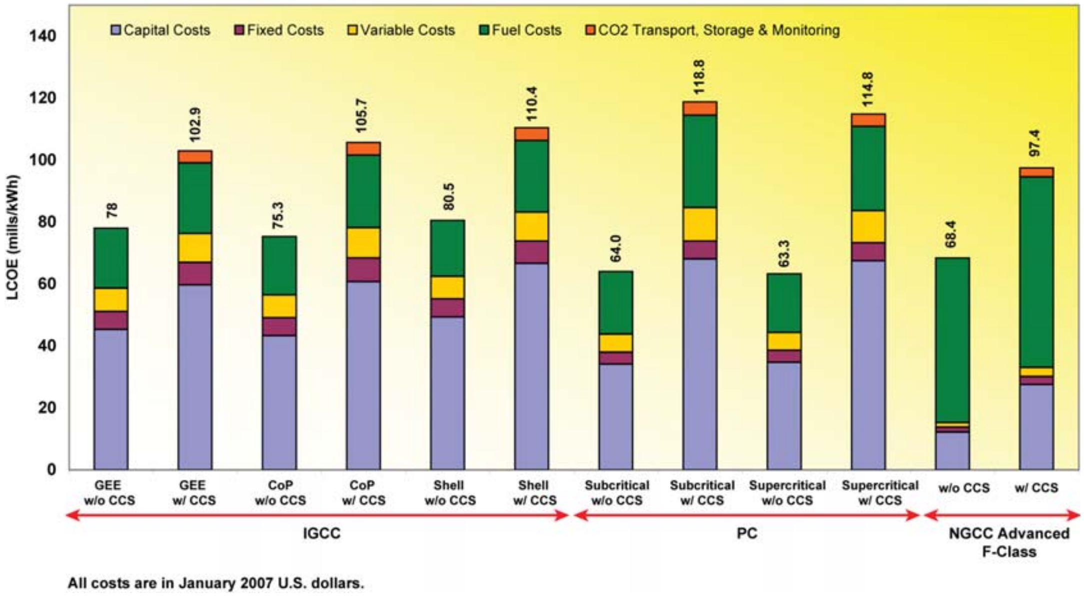
Cost-of-electricity (COE), which accounts for both efficiency and capital cost, is levelized over a 20-year period and expressed in mills/kWh (one mill is one-tenth of a cent). The electricity cost for cases without CCS ranges from about 63 mills/kWh for PC to 68.4 mills/kWh for NGCC and an average of 77.9 mills/kWh for IGCC.

With CCS, IGCC is the least expensive coal-based option for CO_2 removal with a levelized cost-of-electricity (LCOE) ranging from 102.9 mills/kWh to 110.4 mills/kWh. This is about 9 percent lower than PC plants equipped with CCS, which generate electricity at a cost of 114.8 mills/kWh to 118.8 mills/kWh. Figure 7 breaks out the LCOE costs for each technology case.

The cost of CO_2 avoided was calculated for each CCS case and is shown in Figure 8. On an avoided cost of CO_2 basis, IGCC is the least expensive option overall ($32–$42/ton) while NGCC is the most expensive option ($83/ton).

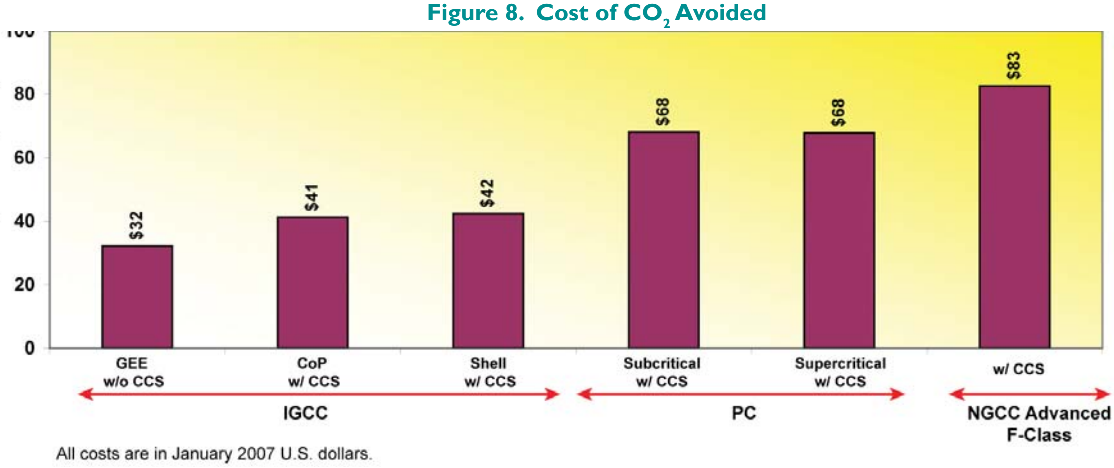
Figure 9 illustrates that at near 80 percent CF, the LCOE for PC cases is less than the LCOE for NGCC cases. With increased CF, the gap in LCOE between IGCC cases and other technologies narrows. For cases with CCS, even at higher CFs, the PC LCOE always remains the highest.

Figure 7. Levelized Cost-of-Electricity



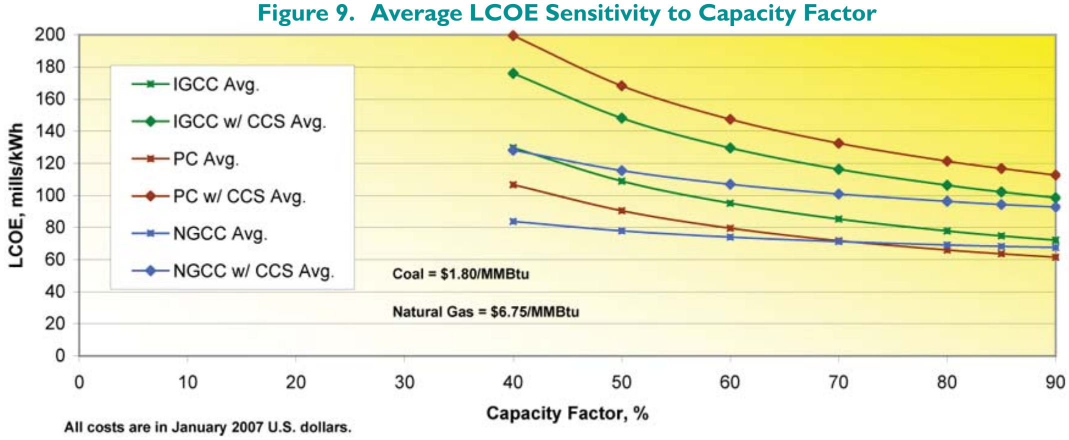
The LCOE sensitivity to fuel costs for the cases with and without CCS is shown in Figure 10. The solid line is the LCOE of NGCC without CCS as a function of natural gas cost. The dashed line is the LCOE of NGCC with CCS as a function of natural gas cost. The points on the lines represent the natural gas cost that would be required to make the LCOE of NGCC equal to the respective PC or IGCC technologies at a given coal cost.

Figure 8. Cost of CO_2 Avoided



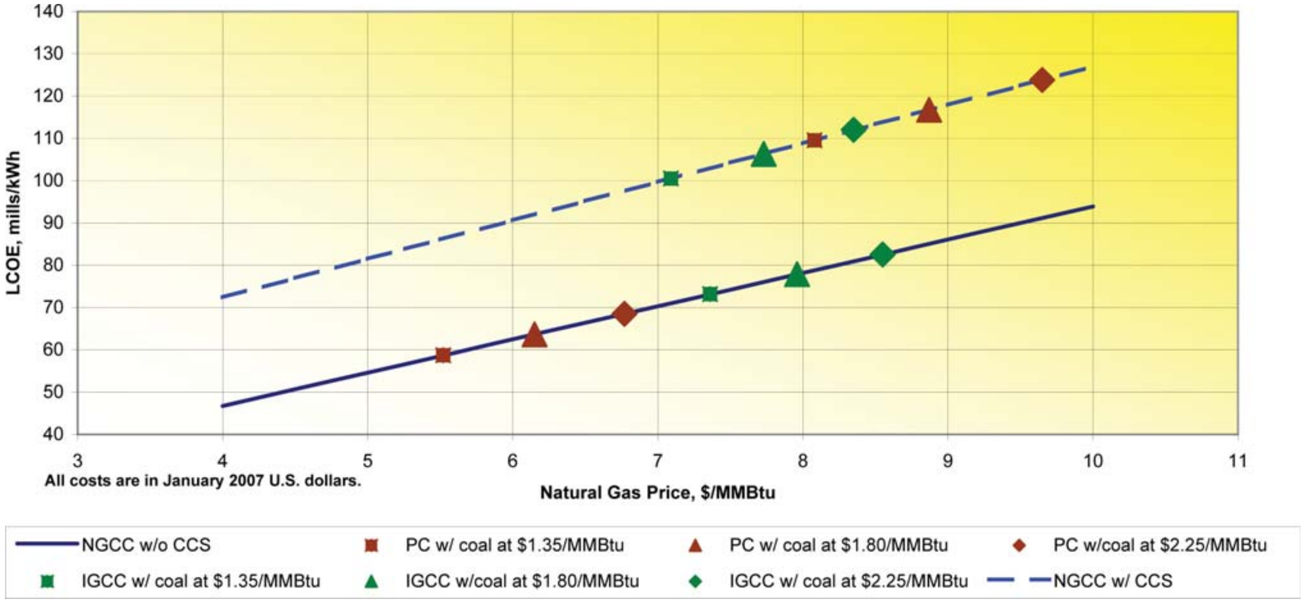
The coal prices shown ($1.35, $1.80, and $2.25/MMBtu) represent the baseline cost and a range of ±25 percent around the baseline.

Figure 9. Average LCOE Sensitivity to Capacity Factor



Without CCS, at the baseline coal cost of $1.80/MMBtu, the LCOE for PC cases equals that of NGCC case at a natural gas price of $6.15/MMBtu; and LCOE for IGCC cases equals that of NGCC case at a gas price of $7.96/MMBtu. With CCS, for the coal-based technologies at a baseline coal cost of $1.80/MMBtu, to be equal to the NGCC case, the cost of natural gas would have to be $7.73/MMBtu (IGCC cases) and $8.87/MMBtu (PC cases).

Figure 10. LCOE Sensitivity to Fuel Costs



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